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| Motion Imagery Interoperability Test Report |

Draft CCSDS Record

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Yellow Book

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DOCUMENT CONTROL

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# INTRODUCTION

## PURPOSE

The purpose of this document is to describe the verification of various operational scenarios for video transmission described in CCSDS 766.1-R-0, Proposed Draft Recommended Standard for Digital Motion Imagery (DMI). All of the use cases stated in the DMI are currently in use on the International Space Station or are in common use for video transmission by the television and streaming media industries. Therefore, discreet testing or prototyping of use case scenarios from the DMI are not required.

## SCOPE

The scope of this document is validation of both non-compressed and compressed digital video systems for spacecraft applications and space to ground transmission. This includes standard definition and high definition video signals.

MPEG-4 Part 10 is part of the validation. For MPEG-4, compressed video data rates vary from 0.5 to 25 Mbps.

 JPEG2000 video compression for real-time transmission has not been utilized in any spaceflight system, but has been included in the DMI. The DMI references that JPEG2000 is not practical for transmission due to the higher bandwidth, compared to MPEG-4. JPEG2000 recordings will be transmitted by file transfer methods in use daily for all types of files. Protocols for JPEG 2000 transmission were standardized in Fall 2013, but true interoperability between different vendors has only been demonstrated in 2015. Because of this and the bandwidth requirements of JPEG2000, no implementations have been made of JPEG2000 in spacecraft and none are currently planned. NASA conducted a JPEG2000 interoperability test in October 2015 with five vendors. The test demonstrated essentially full interoperability between 3 vendors’ hardware and partial interoperability with the others. As the companies involved in implementing this standard are still evolving their systems, this was an expected result. However, sufficient interoperability was demonstrated such that the MIA working group is recommending JPEG2000 transmission be included in the DMI.

Spacecraft-to-spacecraft prototyping and validation are also not part of this yellow book. The DMI does not call out spacecraft-to-spacecraft as a separate operational scenario. Rather, the operational scenarios in the DMI can be applied to spacecraft-to-spacecraft as well as spacecraft-to-ground (3.4.1.7 and 3.4.2.2 of the DMI). The systems needed for transmission and reception of video signals falls beyond the scope of the DMI and are covered under other CCSDS protocols.

Validation of specific applications/use-cases listed in the DMI in Section 3.4.1 has been done.

## APPLICIBILITY

The DMI is applicable to motion imagery applications in spaceflight as listed in 1.1 of the DMI. This includes all use cases and technical specifications as listed in Section 3 of the DMI.

## RATIONALE

The CCSDS Procedures Manual states that for a Recommendation to become a Blue Book, the standard must be tested in an operational manner. The following requirements for an implementation exercise were excerpted from reference [1]:

“At least two independent and interoperable prototypes or implementations must have been developed and demonstrated in an operationally relevant environment, either real or simulated.”

This document outlines the Motion Imagery Applications Working Group’s approach to meeting this requirement for the DMI.

## DOCUMENT STRUCTURE

Section 2 of this document provides a summary and conclusions from validation and testing to date.

Section 3 outlines validation and test goals .

Section 4 provides an overview of what was validated and tested.

Section 5 provides greater detail for each of the scenarios.

Section 6 documents the results.

# SUMMARY CONCLUSIONS/RECOMMENDATION

Current systems onboard the ISS have implemented the protocols listed in the DMI for Standard Definition and High Definition video acquisition and transmission. The exception is the use of JPEG2000 video encoding technology for real-time transmission as detailed in the Scope of this document (1.2). With this exception, the International Space Station is (ISS) serving as a daily application of the DMI . Video being acquired and transmitted from the ISS, regardless of which agency’s cameras are acquiring it, is being distributed as required to every space agency participating in ISS activities and to the public through the media using H.264 video compression. H.264 decoders compliant with the H.264 standard are capable of decoding all the resolutions and frame rates listed in the DMI.

JPEG2000 interoperability testing was conducted in October 2015 and January 2016. The first test was conducted in a lab environment to establish basic interoperability. The second test was conducted with encoders connected to the International Space Station (ISS) avionics simulator at the Johnson Space Center, Sonny Carter Training Facility. This test included transmitting the signal to a Tracking Data and Relay Satellite, receiving the signal, and verifying the ability to decode the received signal on various vendor’s decoders. Until there is a spacecraft implementation, this is the closest scenario to spaceflight that can be accomplished. Based on the current systems being complaint with the DMI the Motion Imagery Applications Working Group recommends the DMI be promoted to a Blue Book CCSDS Recommended Standard.

# DMI VALIDATION AND TEST GOALS

The goal of the validation is twofold:

1. Demonstrate that current International Space Station (ISS) video systems are in compliance with the DMI for several of the applications/use-cases.
2. Prototype applications/use-cases that are not currently being used in operations from the ISS or any other spacecraft. The prototype is to use simulation systems available for testing ISS components on the ground. This will provide an adequate simulation of an existing spacecraft system so as to understand the characteristics of the non-flown applications and use-cases.

# VALIDATION AND TEST OVERVIEW

## General

Most of the standards in the DMI have been adopted for new video systems onboard the ISS, providing a daily proof of concept and operation using the standards listed. This is not coincidental as members of the MIA have been involved in the development of these new systems. These systems are considered to be a successful implementation of the DMI as they are considered acceptable for their respective application by the end users. The DMI Section 2 states the video quality of a system is not measured by application of the DMI, but rather by users of the system. That is, it is considered a success if the end user finds the quality to be acceptable for their purpose. Based on that measure of success, each of the applications listed in Section 4 is successful.

The h.264 encoders and decoders used in the applications listed below in 4.1 are independent implementations from the h.264 specification (different make and model encoders/decoders).

## Summary of Tests

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Test  | Application | Resolution | Encoding | Frame Rate | Spacecraft | Destination |
| 1 | Personal Video Conferencing | 320 x 240 to 1280 x 720 | MPEG-4 | 10 - 60 | ISS | Various, depending upon crew nationality |
| 2 | Medical Conferencing | 320 x 240, 640 x 480, 768 x 576, 1280 x 720 | MPEG-4 | 10- 60 | ISS | NASA, ESA, RSA, JAXA |
| 3 | Situational Awareness | 640 x 480, 768 x 576, 1280 x 720 | MPEG-4, JPEG2000 | 25 - 60 | ISS | NASA, ESA, RSA, JAXA |
| 4 | Public Affairs | 640 x 480, 768 x 576, 1280 x 720 | MPEG-4 | 24, 25, 60 | ISS | NASA, ESA, RSA, JAXA |
| 5 | High Resolution Digital Imaging | 1920 x 1080 and above | NA | 24 - 60 | ISS | NASA, JAXA |
| 6 | JPEG2000 Transmission | 1280 x 720 ad above | JPEG2000 | 24-60 | NA | Prototype Testing |

NOTE – H.264 Part 10 lists resolutions from 128 x96 to 4096 x 2304. This is below and above any resolution listed for real-time transmission in the DMI. Depending upon resolution, H.264 Part 10 lists frame rates up to 145 FPS, far exceeding any frame rates listed in the DMI. As H.264 Part 10 is a decoding standard, it is up to each encoder manufacturer to produce compliant encoders. Not all decoders can decode all resolutions and frame rates that are possible within H.264 Part 10. End users should verify the make and model H.264 Part 10 decoder utilized can decode the resolutions and frame rates required for a particular application.

# VALIDATION PLAN DETAILS

NOTE – The DMI is clear that this is not a quality standard. In Section 2, OVERVIEW, of the DMI it states quality is based on the requirements of the end-user and they will have to work in conjunction with system engineers to ensure adequate video quality for their application.

## Test #1 – PERSONAL VIDEO CONFERENCING

### SCENARIO

Perform Personal Video Conferencing using laptop computers (DMI 3.4.1.2, 3.4.2.1a, 3.4.3, 3.4.4.2, 3.4.5, 3.5.1, 3.6).

The connectivity for the laptops runs through the ISS LAN to the Avionics suite, then through the Tracking Data and Relay Satellite System (TDRSS) downlink to White Sands New Mexico, to the Johnson Space Center, then to NASA/ESA/RSA/JAXA circuits and in some cases to the public Internet.

### RESULTS

Laptops are used on a regular basis for Personal Video Conferencing. They use established network protocols for communication. The video is being encoded as MPEG-4. Variable frame rates are employed, depending upon bandwidth issues. ISS crewmembers routinely communicate with family members in their home countries.

## TEST #2 MEDICAL CONFERENCING

### SCENARIO

Hold Medical Conferences using a variety of video systems (DMI 3.4.1.3, 3.4.2.1b, 3.4.3, 3.4.4.2, 3.4.5, 3.5.1, 3.6).

Participating space agencies are NASA, RSA, ESA, and JAXA.

### RESULTS

Laptops are used for Medical Conferencing, as well as other video systems onboard the ISS. The use of laptops for Medical Conferencing is the same as Personal Video Conferencing with the exception that the video data streams are restricted. This is done on the ground as the data stream is processed at the Johnson Space Center. A variety of resolutions and frame rates have been employed with MPEG-4 encoding.

Both Standard Definition (SD) (320 x 240, 640 x 480, 768 x 576) and High Definition (HD) (1280 x 720) video systems have been used for Medical Conferences. The current SD system onboard the ISS is a multi-channel system that was upgraded during the Obsolescence Drive Avionics Replacement (ODAR) project for ISS. The Integrated Communications Unit (ICU) contains an Audio/Video Interface Card (AVIC) which digitizes incoming video, compresses it using MPEG-4, then interfaces to the Internet Protocol (IP) portion of the ISS Avionics Package. For purposes of transmission, the MPEG-4 video is encapsulated as a video Transport Stream (TS) (CCSDS 766.1-R-0) Section 3.6.1). The video stream is routed with downlink data through TDRSS, White Sands, JSC, and on to the appropriate space agency through currently established links.

The HD system onboard the ISS now uses a stand-alone HD encoder. The output of the encoder is an IP formatted video TS, which is in compliance with CCSDS 766.1-R-0.

## TEST #3 SITUATIONAL AWARENESS

### SCENARIO

Use of SD and HD video systems for situational awareness (DMI 3.4.1.4, 3.4.2.1c, 3.4.3, 3.4.4.2, 3.4.5, 3.5.1, 3.6).

Participating space agencies are NASA, RSA, ESA, and JAXA.

### RESULTS

The current SD and HD video systems on-board the ISS are used for Situational Awareness. This includes docking maneuvers for approaching spacecraft as well as daily operations on ISS. As mentioned in 5.2, those are compliant with CCSDS 766.1-R-0, Section 3.6.1. When the video is received at JSC, it is distributed to the other space agencies over existing links as required.

## TEST #4 PUBLIC AFFAIRS

### SCENARIO

Use of SD and HD video systems for Public Affairs (DMI 3.4.1.5, 3.4.2.1d, 3.4.3, 3.4.4.2, 3.4.5, 3.5.1, 3.6).

Participating space agencies are NASA, RSA, ESA, and JAXA.

### RESULTS

The current SD and HD video systems on-board the ISS are used for Public Affairs broadcasts on a daily basis. As mentioned in 5.2, those are compliant with CCSDS 766.1-R-0, Section 3.6.1.

## TEST #5 HIGH RESOLUTION DIGITAL IMAGING

### SCENARIO

Acquire High Resolution Digital Imaging and transfer files to end-users (DMI 3.4.1.6, 3.4.2.1E, 3.4.3, 3.4.5, 3.5.1, 3.7).

Participating space agencies are NASA and JAXA.

### RESULTS

Various cameras from NASA and JAXA have been used to acquire High Resolution Digital Imaging. The NASA camera has been a Nikon D3 camera shooting 1920 x 1080 video as well as higher resolution time-lapse sequences. The JAXA camera is a Canon C500 4K camera. In both cases, files have been successfully transferred to NASA and JAXA users by utilizing standard file transfer protocols compliant with CFDP Class 1 and Class 2 transfer protocols.

## TEST #5 JPEG2000 INTEROPERABILITY TESTING

### SCENARIO

Confirm interoperability of JPEG2000 encoding and decoding from multiple vendors

The participating space agency is NASA.

### RESULTS

Encoders and decoders from five vendors were tested in the NASA Imagery Experts Group Digital Television (DTV) test facility for interoperability. An 80% success rate was achieved between the vendors, excluding back-to-back encoding and decoding from the same vendor. Some level of success was achieved between all the vendors with three vendors having almost complete compatibility between each other at all data rates tested.

# SCENARIO RESULT DETAILS

## SCENARIO #1 – PERSONAL VIDEO CONFERENCING

**Summary**

|  |  |  |
| --- | --- | --- |
| 1 | Report Date |  |
| 2 | Program Under Test | Digital Motion Imagery 766.1-R-0 |
| 3 | Test Case Number | 1 – Personal Video Conferencing |
| 4 | Agencies Participating | NASA, RSA, ESA, JAXA |
| 5 | Agency Responsible for Generating Video  | NASA, RSA, ESA, JAXA |
| 6 | Producing Test Engineer |  |
| 7 | Agency Responsible for Receiving Video | NASA, RSA, ESA, JAXA |
| 8 | Receiving Test Engineer |  |
| 9 | Spacecraft | ISS |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Currently being done between ISS crewmembers and ground participants |

**Details**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics (Appendix A DMI) |
| 2 | NASA | 320x240 | 15 | 0.5 Mbps | A5-1,3 A6-1 A7-2,4 A9-1 A10-1,2,3,4  |
| 3 | ESA | 320x240 | 15 | 0.5Mbps | A5-1,3 A6-1 A7-2,4 A9-1 A10-1,2,3,4 |
| 4 | RSA | 320x240 | 15 | 0.5Mbps | A5-1,3 A6-1 A7-2,4 A9-1 A10-1,2,3,4 |
| 5 | ESA | 1280X720 | 60 | 1.1Mbps | A5-2 A6-1 A7-2, 4 A9-1 A10-1,2,3,4 |

## SCENARIO #2 MEDICAL CONFERENCING

**Summary**

|  |  |  |
| --- | --- | --- |
| 1 | Report Date |  |
| 2 | Program Under Test | Digital Motion Imagery 766.1-R-0 |
| 3 | Test Case Number | 2 – Medical Conferencing  |
| 4 | Agencies Participating | NASA, RSA, ESA, JAXA |
| 5 | Agency Responsible for Generating Video  | NASA, RSA, ESA, JAXA |
| 6 | Producing Test Engineer |  |
| 7 | Agency Responsible for Receiving Video | NASA, RSA, ESA, JAXA |
| 8 | Receiving Test Engineer |  |
| 9 | Spacecraft | ISS |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Currently being done between ISS crewmembers and ground participants |

**Details**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics |
| 2 | NASA | 640X480 | 30 | 8.0 Mbps | A5-1,3 A6-2 A7-2,4 A9-2 A10-1,2,3,4  |
| 3 | ESA | 640x480 | 30 | 8.0Mbps | A5-1,3 A6-2 A7-2,4 A9-2 A10-1,2,3,4 |
| 4 | RSA | 640x480 | 30 | 8.0Mbps | A5-1,3 A6-2 A7-2,4 A9-2 A10-1,2,3,4 |
| 5 |  |  |  |  |  |

## SCENARIO #3 SITUATIONAL AWARENESS

**Summary**

|  |  |  |
| --- | --- | --- |
| 1 | Report Date |  |
| 2 | Program Under Test | Digital Motion Imagery 766.1-R-0 |
| 3 | Test Case Number | 3 – Situational Awareness |
| 4 | Agencies Participating | NASA, RSA, ESA, JAXA |
| 5 | Agency Responsible for Generating Video  | NASA, RSA, ESA, JAXA |
| 6 | Producing Test Engineer |  |
| 7 | Agency Responsible for Receiving Video | NASA, RSA, ESA, JAXA |
| 8 | Receiving Test Engineer |  |
| 9 | Spacecraft | ISS |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Routine daily ISS Operations |

**Details**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics |
| 2 | NASA | 640x480 | 30 | 1.0 & 8.0 Mbps | A5-1,3 A6-3 A7-2,4 A9-3 A10-1,2,3,4  |
| 3 | NASA | 1280x720 | 60 | 8.O Mbps | A5-2,3 A6-3 A7-2,4 A8-1,2,3,4,5,6,7,8 A9-3 A10-1,2,3,4 |
| 4 | ESA | 640x480 | 30 | 8 Mbps | A5-1,3 A6-3 A7-2,4 A9-3 A10-1,2,3,4  |
| 5 | RSA | 768x576 | 60 | 4.2 Mbps | A5-1,3 A6-3 A7-2,4 A9-3 A10-1,2,3,4 |
| 6 | ESA | 1280x720 | 60 | 8 Mbps | A5-2,3 A6-3 A7-2,4 A8-1,2,3,4,5,6,7,8 A9-3 A10-1,2,3,4 |

## SCENARIO #4 PUBLIC AFFAIRS

**Summary**

|  |  |  |
| --- | --- | --- |
| 1 | Report Date |  |
| 2 | Program Under Test | Digital Motion Imagery 766.1-R-0 |
| 3 | Test Case Number | 4 – Public Affairs |
| 4 | Agencies Participating | NASA, RSA, ESA, JAXA |
| 5 | Agency Responsible for Generating Video  | NASA, RSA, ESA, JAXA |
| 6 | Producing Test Engineer |  |
| 7 | Agency Responsible for Receiving Video | NASA, RSA, ESA, JAXA |
| 8 | Receiving Test Engineer |  |
| 9 | Spacecraft | ISS |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Routine daily ISS Operations |

**Details**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics |
| 2 | NASA | 640x480 | 30 | 8.0 Mbps | A5-1,3 A6-4 A7-2,4 A9-4 A10-1,2,3,4  |
| 3 | NASA | 1280x720 | 60 | 8.O Mbps | A5-2,3 A6-4 A7-2,4 A8-1,2,3,4,5,6,7,8,9 A9-4 A10-1,2,3,4 |
| 4 | ESA | 1280x720 | 60 | 8.0 Mbps | A5-2,3 A6-4 A7-2,4 A8-1,2,3,4,5,6,7,8,9 A9-4 A10-1,2,3,4 |
| 5 | RSA | 1280x720 | 60 | 8.0 Mbps | A5-2,3 A6-4 A7-2,4 A8-1,2,3,4,5,6,7,8,9 A9-4 A10-1,2,3,4 |

## SCENARIO #5 HIGH RESOLUTION DIGITAL IMAGING

**Summary**

|  |  |  |
| --- | --- | --- |
| 1 | Report Date |  |
| 2 | Program Under Test | Digital Motion Imagery 766.1-R-0 |
| 3 | Test Case Number | 5 – High Resolution Digital Imaging |
| 4 | Agencies Participating | NASA, JAXA |
| 5 | Agency Responsible for Generating Video  | NASA, JAXA |
| 6 | Producing Test Engineer |  |
| 7 | Agency Responsible for Receiving Video | NASA, JAXA |
| 8 | Receiving Test Engineer |  |
| 9 | Spacecraft | ISS |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Downlink file transfers of recorded imagery from Nikon D3s and Canon C500 |

**Details**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics |
| 2 | NASA | 1920x1080 | 30 | NA | A5-1 A6-5 A7-1,3 A9-5 A10-1,2,3,4 (file transfer)  |
| 3 | NASA | 3840x2160 | 30 | NA | A5-1 A6-4 A7-1,3 A9-5 A10 – 1,2,3,4 (file transfer) |
| 4 | JAXA | 3840x2160 | 30 | NA | A5-1 A6-5 A7-1,3 A9-5 A10-1,2,3,4 (file transfer) |
|  |  |  |  |  |  |

## scenario #6 JPEG2000 INTEROPERABILITY TESTING

|  |  |  |
| --- | --- | --- |
| 1 | Report Date | Nov. 2015 |
| 2 | Program Under Test | Digital Motion Imagery 766.1-B-1 |
| 3 | Test Case Number | 6 – JPEG2000 Interoperabilty Testing |
| 4 | Agencies Participating | NASA |
| 5 | Agency Responsible for Generating Video  | NASA |
| 6 | Producing Test Engineer | Walt Lindblom |
| 7 | Agency Responsible for Receiving Video | NASA |
| 8 | Receiving Test Engineer | Walt Lindblom |
| 9 | Spacecraft | NA |
| 10 | Results (Pass, Partial Pass, Fail)  | Pass |
| 11 | Variances from Expected Result: | None |
| 12 | Comments | Lab interoperability test and ISS avionics simulator test |

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| 1 | Agency | Resolution | Frame Rate | Data Rate | Applicable Pics |
| 2 | NASA | 1280x720 | 59.94 | 120, 90, & 60 Mbps | A8-1a, 2a, 3a, 4a, 5a, 6a, 7a  |

Test Result Summary:



